Argumentation Skills of Pre-Service Physics Teachers: An Exploration During a STEM Project in Water Turbidity

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Abstract. Pre-service physics teachers (PSPTs) should have an established argumentation skill, a recognized skill in 21st-century education, to support learning. In line with this, the study explored the argumentation skills of PSPTs using an argumentation framework, Toulmin's argument pattern (TAP), to provide a clear view of the argumentation skills of the 39 PSPTs who were involved in a four-meeting science, technology, engineering, and mathematics (STEM) project. The study employed a mixed method research design in which the quantitative portion investigated the categories of TAP aspects, and the qualitative portion focused on exploring the argumentation patterns of the PSPTs. The data for this study was derived from the STEM project worksheets answered by the pre-service teachers. Quantitative analysis revealed PSPTs' argumentation aspect to be high regarding the claim aspect (97.44%) and data aspect (94.87%). Meanwhile, the warrant aspect (53.85%) is moderate, backing (20.51%) is low, and the rebuttal aspect (2.56%) is deficient. On the other hand, the qualitative analysis showed that PSPTs make four argumentation patterns: claim & data (C-D); claim, data & warrant (C-D-W); claim, data, warrant, & backing (C-D-W-B); and claim, data, & rebuttal (C-D-R). Considering TAP, quantitative and qualitative findings imply that PSPTs' argumentation skills still need to be developed, particularly on low-level aspects and in constructing a solid argument following the claim, data, warrant, backing, and rebuttal pattern.

Keywords: Argumentation skill, STEM, Toulmin's argument pattern, pre-service physics teachers

Introduction

Teachers' knowledge and skills greatly influence students' success (Diniya et al., 2021). Concerning this, pre-service teachers' training must include developing understanding and establishing the skills necessary to nurture students' 21st-century skills (Yokhebed, 2019). In the Indonesian context, international reports, such as PISA, imply the need for teachers to exert more significant effort in developing the 21st-century skills of learners (Mu'minah & Aripin, 2019). Hence, pre-service teachers must establish and build their skills to effectively facilitate learners in gaining 21st-century skills.

One of the 21st-century skills is critical thinking. Critical thinking is very important for undergraduate students because it provides them with provisions to face various...
advances in science, especially in the 21st century (Amin et al., 2023). The ability to identify relationships between statements, concepts, data descriptions, information, or opinions indicates critical thinking (Amin et al., 2023). Another indicator of critical thinking includes argumentation. The term argumentation is defined as the ability to express ideas or opinions by providing supporting evidence, data, and theory so that conclusions can be drawn (Erduran, 2018; Senjaharmini et al., 2019; Roja et al., 2020; Suliyanah et al., 2020; Hasanah et al., 2022).

Argumentation skills encourage critical thinking skills (Mellenia & Admoko, 2022) and develop a strong understanding of concepts, leading to improved critical thinking skills (Noviyanti et al., 2019). Similarly, Rahayu and colleagues (2023) claimed that students can obtain a conceptual understanding of scientific concepts through argumentation. Thus, a fully developed argumentation ability indicates success in teaching and learning practices in the classroom (Chen et al., 2019). In physics education, argumentation also serves as a measure of the reasoning process and understanding of physics material (Sudarmo et al., 2018). Pre-service teachers, including PSPTs, have been recognized as guides in classroom-based argumentation (Cenk & Yalman, 2022). PSPTs need to master argumentation skills because they can increase students' understanding of the science processes (Amalia et al., 2019). Using correct argument structures and attributes motivates future teachers to use practice, impacting prospective students' learning generation (Castro et al., 2021). For this reason, it is imperative to integrate activities that foster argumentation skills for teacher training.

Toulmin’s argumentation pattern (TAP) is a model that clearly defines and illustrates argumentation skills. TAP consists of several aspects, including the essential aspect consisting of claim, data, and warrant, as well as additional aspects consisting of backing, qualifier, and rebuttal, which function to strengthen arguments (Toulmin, 2003; Kutluca et al., 2014; Suartha et al., 2020; Admoko et al., 2021; Fakhriyah et al., 2022). TAP includes claims that are conclusions whose merits must be established; data are facts used as evidence to support claims; warrants are reasons that justify the connection between data and claims; backing is the basic assumption that provides justification for a particular warrant; and rebuttal indicates certain circumstances where the claim is untrue and invalid (Hakim et al., 2022). TAP is a technique used to assess, group, and demonstrate the quality of an argument (Widhi et al., 2021). TAP can make it easier to measure, identify, and analyze the quality of argumentation so that the level of argumentation ability can be known (Irvan & Admoko, 2020). Thus, TAP, when used as a measure, could effectively inform the argumentation skills of PSPTs.

Meanwhile, STEM learning could provide a promising avenue for measuring argumentation abilities using TAP (Gülen & Yaman, 2019). STEM learning is learning that integrates four disciplines: Science, Technology, Engineering, and Mathematics, to solve real-life problems (Krajcik & Delen, 2017; Bozkurt et al., 2019; Indarwati et al., 2021; Syahiddah et al., 2021). It is an approach that provides learning knowledge (science), the ability to design a tool (technology), the ability to operate a tool and design stages to solve a problem (engineering), and understand quantities and units in calculations (mathematics) (Santoso & Arif, 2021). Applying STEM learning through project activities can increase understanding of concepts, which can help build quality arguments (Paramita et al., 2020). Applying STEM learning to specific topics can improve the readiness of PSPTs in actual classroom activities (Sulaeman et al., 2022). STEM learning can develop skills in argumentative discussions to meet the needs of the 21st century (Paramita et al., 2019).

Water turbidity, a water quality parameter, can affect aquatic life in the water, ecosystems, and the availability of raw water for humans (Tomperi, et al., 2020). For the future of water conservation, students must be educated about water issues and turbidity. In addition, the topic is addressed in goal 6 of the sustainable development goals (ensure access to water and sanitation for all). Therefore, environmental issues must be taught in
a class using a suitable teaching method. A study has found that a project-based learning model based on contextual problems can improve students' ability to solve environmental issues (Retnowati et al., 2020). In project-based learning, learners build knowledge by completing meaningful projects and developing real-world products. It is crucial, however, to integrate project-based learning into STEM education since learning nowadays must meet the needs of the globalization era (Roslin et al., 2022). As students engage in real-life problems in STEM, authentic projects ignite their curiosity and generate excitement and empathy. STEM instruction typically uses the engineering design process (EDP) as an instructional framework (Siew, 2017). A student in an EDP course follows the same process an engineer, scientist, or mathematician would use in solving a problem. As a result of STEM teaching with a project-based learning model, students should be able to develop their argumentation abilities, leading to them developing high-order thinking skills. The use of EDP involves experience to solve real-life problems. The EDP step starts with defining a problem and ends with developing a solution that can be used to improve argumentation skills (Putra et al., 2023b). Given these facts and learning opportunities in STEM projects, it would be a good opportunity to investigate the argumentation skills of pre-service teachers during a STEM project.

The background highlights the need for PSPTs to establish and build skills, particularly argumentation skills, to effectively facilitate learners in gaining 21st-century skills, which makes it imperative to integrate activities that foster argumentation skills for teacher training. TAP, an established argumentation model, could reveal the argumentation skills of PSPTs. Meanwhile, STEM learning could provide a promising avenue for measuring argumentation abilities among PSPTs. In line with this, the study aimed to explore the argumentation skills of PSPTs using TAP to give a clear view of the argumentation skills of PSPTs involved in a STEM project in water turbidity. Furthermore, it aimed to contribute to the existing literature because more research needs to explore the aspects and patterns of argumentation among PSPTs.

**Methods**

This research employed a simple mixed-method design. The quantitative analysis investigated the categories of TAP aspects, and the qualitative analysis focused on exploring the argumentation patterns of the PSPTs. Participants of this research were 39 PSPTs who took the Integrated Science course at the Physics Education Department, Mulawarman University, Samarinda, Indonesia. Data was obtained after carrying out four meetings of the STEM project on water turbidity. At the end of each meeting, the PSPTs worked on a worksheet. In the worksheet, PSPTs are directed to form arguments about STEM learning.

After collecting the worksheets, the arguments were collated and subjected to TAP analysis. The categories of PSPTs' TAP aspects are determined by converting the number of occurrences of each TAP aspect into a percentage score. The percentage score is calculated from the number of occurrences of each TAP aspect divided by the number of samples and then multiplied by one hundred. Finally, the values obtained are adjusted to the guidelines in Table 1 to determine each TAP aspect’s category.
After the quantitative analysis, a qualitative analysis was carried out to determine PSPTs' argumentation patterns. Indicators of the emergence of each TAP aspect can be seen in the TAP rubric in Table 2. With the rubric, the research team met to discuss the codes and condense them into concepts to allow for the grouping of the raw data. Throughout data analysis, a constant comparative analysis was used to look for consistencies and differences between researchers' coding and between data sources. Research meetings were conducted to provide opportunities to discuss and resolve the reasoning behind such differences in coding. After the completion of coding, the researchers examined tentative assertions that could be made based on the data. Following this comparative analysis, the researchers determined the argumentation patterns.

Table 1. Guidelines for Argumentation Skill Level Categories

<table>
<thead>
<tr>
<th>Average Score (%)</th>
<th>Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>80 &lt; x ≤ 100</td>
<td>Very High</td>
</tr>
<tr>
<td>60 &lt; x ≤ 80</td>
<td>High</td>
</tr>
<tr>
<td>40 &lt; x ≤ 60</td>
<td>Moderate</td>
</tr>
<tr>
<td>20 &lt; x ≤ 40</td>
<td>Low</td>
</tr>
<tr>
<td>0 ≤ x ≤ 20</td>
<td>Very Low</td>
</tr>
</tbody>
</table>

Table 2. TAP Rubric

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Indicators</th>
</tr>
</thead>
<tbody>
<tr>
<td>Claim</td>
<td>Able to write arguments/opinions in writing</td>
</tr>
<tr>
<td>Data</td>
<td>Able to write any information about statements related to the claim</td>
</tr>
<tr>
<td>Warrant</td>
<td>Able to explain the relationship of known information by writing other forms of statements to make the claim stronger</td>
</tr>
<tr>
<td>Backing</td>
<td>Able to provide additional, stronger evidence to support the warrant</td>
</tr>
<tr>
<td>Rebuttal</td>
<td>Able to refute or show an exception to the argument made</td>
</tr>
</tbody>
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Results and Discussion

Argument Skill of PSPTs

Based on the results of the TAP analysis, the arguments made by the 39 PSPTs have claims and data, as well as several warrants, backings, and rebuttals. Specifically, there are 38 claims, 37 data, 21 warrants, 8 backings, and 1 rebuttal. Figure 1 shows the percentage scores of the PSPTs' TAP aspects.
The PSPTs’ arguments include the five aspects of TAP. The analysis of the PSPTs arguments reveals that the claim aspect (97.44%) and the data aspect (94.87%) were classified as very high. The warrant aspect (53.85%) was moderate, the backing aspect (20.51%) was low, and the rebuttal aspect (2.56%) was deficient. The result indicates that the PSPTs can make arguments that contain the essential components - claim, data and warrant. However, PSPTs are hard to make arguments with additional aspects - backing and rebuttal. The result could be attributed to the limited exposure of PSPTs in activities that allow them to develop arguments, may it be simple or complex arguments, which resulted in the need to further develop the argumentation skills of the PSPTs, most especially along with backing and rebuttal.

The result follows previous research where pre-service teachers could only form claims, data, and warrants, but they could not back up and rebuttal (Cenk & Yalman, 2022). Likewise, Syerlina’s (2018) research concluded that the backing and rebuttal aspects were fewer in number than the claim and data aspects. The result further implies that PSPTs are not yet equipped with the skills to formulate good arguments in accordance with the TAP aspects, most especially along with backing and rebuttal.

**Argument Pattern of PSPTs**

The PSPTs’ argumentation pattern was obtained by carefully analyzing their arguments. The results obtained revealed the emergence of four argumentation patterns. These patterns are 1) claim & data (C-D); 2) claim, data & warrant (C-D-W); 3) claim, data, warrant, & backing (C-D-W-B); and 4) claim, data, & rebuttal (C-D-R). Out of 39 PSPTs, there are 14 responses with the C-D pattern, 13 answers with the C-D-W pattern, 8 answers with the C-D-W-B pattern, 1 answer with the C-D-R pattern, and 3 of them only consisted of 1 TAP aspect and did not form an argumentation pattern. Figure 2 shows an example of a C-D.
Claim: "In my opinion, STEM has helped us in solving the problems of this project."

Data: "The role of STEM in this project is to provide students with concepts, principles, and techniques from science, technology, and engineering are used in an integrated manner in the development of products, processes, and systems and can especially direct students in finding solutions used to solve problems in everyday life."

Figure 3 exhibits an example of the C-D-W pattern.
Claim:
"The STEM approach helped solve the problems in this project."

Data:
"The STEM approach is an interdisciplinary approach to learning, where various science, technology, engineering, and mathematics concepts are combined in a project."

Warrant:
"The science in this project is related to natural science when we make a project to solve environmental problems at our campus, about water problems. In terms of technology, this project has utilized existing technology, such as when measuring water turbidity through the lux meter application. On the engineering aspect, we use certain techniques in making tools to measure the level of turbidity of water and water filtration equipment. In the Mathematics aspect, this project also includes mathematics, such as calculating the debit of filtered water."

Figure 4 exhibits an example of the C-D-W-B pattern.

Claim:
"STEM has an important role in this project because the project creation process requires several fields of knowledge."

Data:
"STEM is a field of Science, Technology, Engineering, and Mathematics."

Warrant:
"The use of science aims to underlie the project because when conducting experiments, a theory is needed to prove the project. The use of technology aims to assist the project in terms of finding a solution to the problem. The use of Engineering aims to assist in the project creation process. The use of Mathematics aims to calculate and prove data from these problems."

Backing:
"So, the use of STEM plays a very important role in this project to solve existing problems."

Figure 5 exhibits an example of the C-D-R pattern.

**Figure 5.** The C-D-R pattern

Claim:
"In my opinion, the water filters that have been made do not fully comply with STEM standards, which we know means STEM is the integration of science, technology, engineering, and mathematics."

Data:
"The elements that are fulfilled in my opinion are the elements of Science reflected in materials and the use of tools, Engineering in the process of working turbidity tools, and Mathematics when calculating turbidity and making graphs."

Rebuttal:
"However, for technology, I don't think it is sufficient because if the tool is used repeatedly, the water quality will return to normal and the technology that is applied, in my opinion, is only for the application of a lux meter and light to measure water turbidity."

The results of the argumentation patterns were further converted into percentages. The percentage of argumentation patterns of pre-service physics teachers can be seen in Figure 6.
Based on the analysis of PSPT’s arguments, it can be seen that the pattern that appears most frequently is the C-D pattern, with a percentage of 36%, followed by the C-D-W, with a percentage of 33%, then the C-D-W-B pattern, with a percentage of 20%, then the C-D-R pattern with a percentage of 3%, and 8% are answers that do not form an argumentation pattern or only consist of 1 TAP aspect. It can be seen that the most straightforward pattern, C-D, has the most significant percentage, followed by the C-D-W, C-D-W-B, and C-D-R patterns. It can be seen that patterns containing backing and rebuttal aspects have a small percentage compared to C-D and C-D-W patterns. The result indicates that the PSPTs could only utilize simple argumentation patterns and have difficulty producing complex argumentation patterns. The result could also be attributed to the limited exposure of PSPTs in activities that train them to construct arguments with complex and complete patterns that integrate all the aspects of TAP.

The results follow previous research where pre-service teachers' arguments were limited to basic arguments, and pre-service teachers could not form arguments with more complex patterns up to rebuttal (Setiawati & Nurlaelah, 2017). The aspects of backing and rebuttal still appear very little in the arguments made by pre-service teachers. An argument has high quality if the backing and rebuttal aspects appear frequently (Abdurrahman & Nurmatin, 2023). Based on research conducted by Zhao (2021), the limitations of PSPTs in constructing arguments are that they are not well prepared, especially in producing a rebuttal to the argument. Pre-service teachers cannot argue well due to a lack of knowledge or argumentative skills (Tan et al., 2017). The ability to form arguments can increase when PSPT knows the relevant argumentation process (Cenk & Yalman, 2022). The result further implies that PSPTs’ argumentation abilities are limited to simple arguments consisting of claim, data, and warrant aspects. No PSPT can form arguments with the five aspects of TAP. Thus, PSPTs’ ability to form arguments with complex patterns is still lacking.

### Relation Between STEM Project with Argumentation Skills

After four STEM-Project meetings, the PSPTs were directed to form an argument regarding the STEM learning that had been implemented. STEM-EDP can facilitate PSPTs to actively discuss and collaborate, especially in developing argumentation skills. EDP activities support each individual in building arguments in science class (Putra et al., 2023a). In previous research, the EDP model was integrated with TAP and was proven to improve pre-service science teachers’ critical thinking skills (Tüysüz et al., 2023), which can also facilitate PSPTs in building arguments.
In the project that has been implemented, the relationship between the STEM-EDP stages and the TAP aspects is as follows. At the define stage, the PSPTs can determine the claim in his argument (identify the client's needs and constraints at the define stage). At the define stage, it is used to define a phenomenon or problem (Ulum et al., 2021), so at this stage, PSPTs are limited to writing complex arguments and only reach the claim aspect. At the learn, plan, and try stages, PSPTs can add data aspects to their arguments (adding information at the learn and plan stages and obtaining information from prototype results at the try stage). At the test stage, the PSPTs can add a warrant to the argument (linking the claims made at the define stage with the data obtained at the learn, plan, and try stages). At the decide stage, the PSPTs can add a backing aspect (based on the warrant appearing at the test stage) and a rebuttal aspect (an objection if the product does not meet the client's criteria or needs). At the decide stage, the product design will be decided whether it meets the criteria or obstacles are found. Then, the product design can be optimized (Ulum et al., 2021). So, the decide stage in the EDP model can facilitate PSPTs in building arguments with complex patterns. The relationship framework between the stages of the EDP and TAP's aspects is shown in Figure 7.

![Figure 7. Relationship between STEM-EDP and TAP (Wisutama et al., 2022)](image)

The research results show that PSPTs are still not optimal in making arguments with complex patterns (using backing and rebuttal aspects). The causal factor is that PSPTs are still not equipped with the ability to make correct arguments. Apart from that, another factor is the weakness in the worksheet provided. In the worksheet provided, only at the decide stage can PSPT form arguments optimally. At the define, learn, plan, try, and test stages, PSPTs are only limited up to the warrant aspect. The reason why the highest percentage of aspects is only found in claims, data, and warrants.
Conclusion

The argumentation skills of PSPTs after implementing a STEM water turbidity project have been carefully explored in this study. The research results revealed the categories of each aspect of TAP and the argumentation patterns of PSPTs. Based on the results, it can be concluded that the analysis of the PSPTs’ argument showed that the claim aspect (97.44%) and the data aspect (94.87%) were classified as very high. The warrant aspect (53.85%) was moderate, the backing aspect (20.51%) was low, and the rebuttal aspect (2.56%) was deficient. The PSPT's argumentation pattern consists of several patterns: C-D, C-D-W, C-D-W-B, and C-D-R. The argumentation patterns most often appear in PSPTs are the C-D and C-D-W patterns. Based on the analysis results, PSPTs' argumentation skills still need to be developed, particularly on low-level aspects and in constructing a solid argument following the claim, data, warrant, backing, and rebuttal pattern.

Limitation and Further Research

The study contributes to the growing body of knowledge in argumentation by exploring the argumentation skills of PSPTs using TAP. Though integrated into implementing a STEM project, the study was only focused on exploring the categories of each aspect of TAP and the argumentation patterns of PSPTs. Nevertheless, findings lead to new inquiry opportunities that would support the increase in the categories and complexity of PSPTs arguments. Since Toulmin's framework helps communicate the meaning of an argument and evaluate student outcomes, it is recommended that a) curriculum/instructional materials be developed to scaffold the PSPTs in making complex arguments anchored on TAP, and b) TAP as an argumentation guide be introduced by teacher educators not just in integrated science subject but across all science subjects. Though the study has outlined the relationship between argumentation and STEM projects, there is a need to investigate further the effect of STEM projects on PSPTs’ argumentation and also how improved argumentation skills could contribute to the success of PSPTs in STEM projects. Lastly, the study hopes to encourage PSPTs to exert personal effort in establishing their argumentation skills, given that it could indicate critical thinking- one of the 21st-century skills of and for facilitating learners.

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